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CARBON FOOTPRINTING

How does co-product handling affect the carbon footprint of milk? Case study of milk production in New Zealand and Sweden

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Abstract
Purpose This paper investigates different methodologies of handling co-products in life cycle assessment (LCA) or carbon footprint (CF) studies. Co-product handling can have a significant effect on final LCA/CF results, and although there are guidelines on the preferred order for different methods for handling co-products, no agreed understanding on applicable methods is available. In the present study, the greenhouse gases (GHG) associated with the production of 1 kg of energy-corrected milk (ECM) at farm gate is investigated considering co-product handling.
Materials and methods Two different milk production systems were used as case studies in the investigation of the effect of applying different methodologies in co-product handling: (1) outdoor grazing system in New Zealand and (2) mainly indoor housing system with a pronounced share of concentrate feed in Sweden. Since the cows produce milk, meat (when slaughtered), calves, manure, hides, etc., the environmental burden (here GHG emissions) must be distributed between these outputs (in the present study no emissions are attributed to hides specifically, or to manure which is recycled on-farm). Different methodologically approaches, (1) system expansion (two cases), (2) physical causality allocation, (3) economic allocation, (4) protein allocation and (5) mass allocation, are applied in the study.
Results and discussion The results show large differences in the final CF number depending on which methodology has been used for accounting co-products. Most evident is that system expansion gives a lower CF for milk than allocation methods. System expansion resulted in 63–76% of GHG emissions attributed directly to milk, while allocation resulted in 85–98%. It is stressed that meat is an important by-product from milk production and that milk and beef production is closely interlinked and therefore needs to be considered in an integrated approach.
Conclusions To obtain valid LCA/CF numbers for milk, it is crucial to account for by-products. Moreover, if CF numbers for milk need to be compared, the same allocation procedure should be applied.

Keywords Allocation · CF · LCA · Life cycle assessment · System expansion

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1 Introduction

The interest in assessing the carbon footprint[1] (CF) of products (especially foods) has markedly increased during the last few years, and milk and dairy products are no exception. Many dairy companies (e.g. Arla Foods in Denmark and Fonterra in New Zealand) are today calculating the CF, either for the whole company or for products, and in some supermarkets (e.g. Tesco in UK and Casino in France), milk and dairy products are already carrying carbon labels. Consumers also want information on how the products they purchase affect the climate, and a study in UK shows that 50% of the consumers say they want to buy products with lower carbon footprint (FRANK Research Ltd). The recent focus on carbon footprinting has resulted in several initiatives on developing standards and guidelines to harmonise CF calculations (e.g. ISO 14067, the Greenhouse Gas Protocol Initiative on Product Life Cycle Accounting and Reporting Standard by World Business Council for Sustainable Development (WBCSD) and World Resource Institute (WRI)). In addition, there are also more sector specific initiatives, e.g. Carbon Trust developing more detailed guidelines on how to calculate the CF for some product groups and the International Dairy Federation (IDF) in association with the Sustainable Agricultural Initiative (SAI) Platform are leading the development of guidelines on how to assess the CF of dairy products specifically. These initiatives are motivated by the need for several methodological choices to be made in life-cycle carbon accounting, which affect the final results of the CF reporting.

The method used when distributing the environmental burden between the main product and by-products can have a significant impact on the final results of a life cycle assessment (LCA) or CF study (Cederberg and Stadig 2003; Feitz et al. 2007). What methodology to use is also one of the more debated issues in LCA/CF research. There are clear guidelines of the preferred order for different methods for handling co-products in LCA (ISO 2006) or CF (BSI 2008); however, there is not a common shared understanding on when different methods are applicable. In addition, different ways to handle co-products within the same production system can occur.

According to ISO (2006), co-products should be handled according to the stepwise procedure presented below. This order also applies for PAS 2050 (BSI, 2008), except that economic allocation is recommended after system expansion (i.e. “step 3” comes before “step 2”).

Step 1 Wherever possible, allocation should be avoided by

- dividing the unit process to be allocated into two or more sub-processes and collecting the input and output data related to these sub-processes, or
- expanding the product system to include the additional functions related to the co-products.

Step 2 Where allocation cannot be avoided, the inputs and outputs of the system should be partitioned between its different products or functions in a way that reflects the underlying physical relationships between them; i.e. they should reflect the way in which the inputs and outputs are changed by quantitative changes in the products or functions delivered by the system.

Step 3 Where physical relationship alone cannot be established or used as the basis for allocation, the inputs should be allocated between the products and functions in a way that reflects other relationships between them. For example, input and output data might be allocated between co-products in proportion to the economic value of the products.

Dividing a unit process into more sub-processes is not possible for milk production, e.g. to produce milk the cow must produce a calf, and also other inevitable by-products (meat and hides from culled dairy cows). The alternative choice is to apply system expansion. This has only been conducted in a limited number of studies on milk (Cederberg and Stadig 2003; Hospido 2005; Thomassen et al. 2008a). To analyse the environmental burden of milk, allocation has typically been used based on physical causality (e.g., Basset-Mens et al. 2009; Ledgard et al. 2009a; Cederberg and Mattsson 2000), protein content (Gerber et al. 2010) or economic value (e.g., Arsenault et al. 2009; Cederberg and Stadig 2003; Cederberg and Flysjö 2004; Hospido 2005; Thomassen et al. 2008a, b; van der Werf et al. 2009).

As shown by Cederberg and Stadig (2003) the method chosen for co-product handling greatly affects the final results. In their study on system expansion and allocation in milk and beef production, they analysed the environmental impact for milk production at farm gate in Sweden using different methods for co-product handling. Their results showed that 91%, 85% and 63% of the greenhouse gas (GHG) emission were attributed to the milk when applying economic allocation, physical cause–effect allocation and system expansion, respectively (with the difference due to co-products). Consequently, if LCA/CF studies of milk are to be comparable, it is crucial that the co-product handling methodology used is identical.

[1] CF is a term used to describe the total amount of greenhouse gas (GHG) emissions of a process or a product system to indicate their contribution to climate change. It also includes emissions of methane and nitrous oxide, which are of special importance for agricultural products.

The objective with the present paper is to illustrate how different ways of handling co-products affect the final CF result for milk, as also done in Cederberg and Stadig (2003). Here, however, more methods for co-product handling are applied, both on system expansion and allocation. When applying system expansion, it is crucial to identify what alternative products would replace the by-products. This may differ depending on the production system and the geographic origin of the production. Additionally, here, two different milk production systems are analysed (outdoor pasture grazing system in New Zealand (NZ) and mainly indoor housing systems with pronounced share of concentrate feeds in Sweden (SE)). The main goals with the present study are to analyse:

1. the importance of accounting for by-products in LCA/CF of milk, and
2. the difference in results depending on what method is used for co-product handling.

Furthermore, the objective is also to show the risk of giving misleading information when different CF results for milk are compared without a harmonised and uniform method of handling co-products. In addition, the purpose is also to illustrate the important interlink between dairy production and beef production.

2 Materials and methods

The CF for 1 kg of energy-corrected milk (ECM), corrected based on fat and protein (including by-products), at the farm gate in NZ and SE was analysed in Flysjö et al. (2011) and serves as the basis for this study. The conceptual framework for LCA is used but only focusing on the GHG emissions: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The present study includes extraction of raw materials for feed production and other inputs to the milk system, and ends at the farm gate, which usually represents the main part (>80%) of total GHG emissions for production of milk and dairy products (Gerber et al. 2010; Sevenster and de Jong 2008; Hospido 2005; Berlin 2002; Högaas Eide 2002). The calculations have been performed in the LCA software tool SimaPro7 (PRé Consultants bv 2010). Contribution to global warming is calculated using the global warming potential (GWP) for a 100-year time horizon according to IPCC (2007), in CO_2 equivalents (CO_2e): CO_2 1, CH_4 25 and N_2O 298. In both NZ and SE farm systems, the data originate largely from national statistics from 2005, and key figures, such as methane emissions from enteric fermentation (often contributing about 50% of the CF for milk production at farm), are calculated using the same method. The CF for milk at farm gate (including by-products, i.e. 100% of environmental burden is allocated to milk) is calculated at 1.00 kg CO_2e and 1.16 kg CO_2e per kilogram ECM for NZ and SE, respectively (Flysjö et al. 2011). The present paper presents details on production of co-products for NZ and SE dairy systems, and the different methods used for co-product handling are described in Section 2.2.

2.1 System description

The dairy farming system in New Zealand and Sweden differ considerably. Below is given a description for each of the farming systems. The study is conducted using data for the year 2004/2005 for NZ and 2005 for SE.

2.1.1 New Zealand

The dairy sector is one of the most important industries in the New Zealand economy and accounts for close to a quarter of New Zealand's total merchandised export (MAFa). New Zealand has around four million dairy cows (MAFb) producing about 15 million tonnes milk (New Zealand Dairy Statistics) of which approximately 95% is exported, mainly as milk powder and cheese.

The average farm in NZ has 339 cows, which are on pasture all year around. The milk yield delivered for dairy processing is 4,120 kg ECM cow^{-1} $year^{-1}$. The replacement rate (heifers that replace culled cows per year) for dairy cows is 23% (DairyNZ ProfitWatch survey data), and a heifer has its first calf at 24 months. In NZ, a dairy cow has an average of 4.3 lactations (i.e. the average slaughter age is almost 6.5 years for a dairy cow).

The flows of cattle in NZ are illustrated in Fig. 1. The statistical data for cattle represent the 12-month period from July 2004 to June 2005, reported by the New Zealand's Ministry of Agriculture and Forestry (MAFb, MAFc) (these data are in shaded boxes in Fig. 1). The replacement rate was estimated at 18% for beef cows (personal communication, Con Williams, Beef + Lamb New Zealand). The 'animal flows' (arrows in Fig. 1) were estimated/calculated based on the number of dairy cows and heifers and beef cows/heifers/steers/bulls and calves (MAFb), number of slaughtered cattle (MAFc), and the replacement rates. Total number of cows slaughtered were 792,000 (MAFc), and of this, 688,000 were estimated to be culled dairy cows (personal communication, Con Williams, Beef + Lamb New Zealand). Total number of dairy calves born alive was 3,320,000 (MAFb), of which 948,000 were assumed to stay in the dairy systems and to be raised for replacing culled dairy cows after 2 years. About 955,000 of the dairy calves were estimated to enter the beef system and be raised and then slaughtered at 22–28 months at about 300 kg carcass weight (CW). The rest of the dairy calves were slaughtered at an age of 4 days, as there is no economic profit in raising

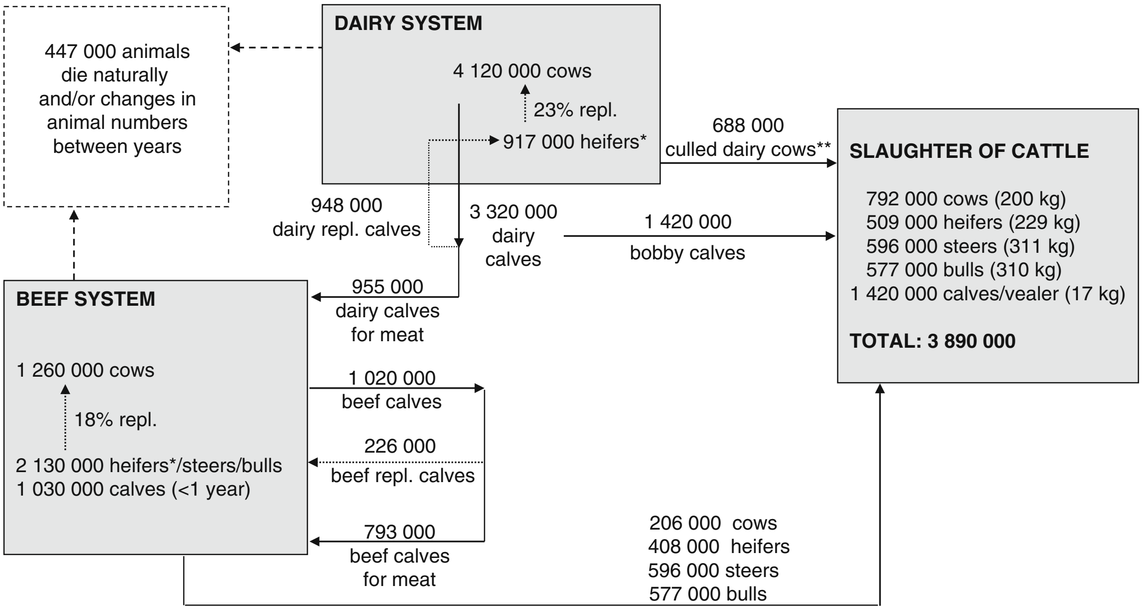

Fig. 1 Illustration of the flows of cattle in New Zealand (*single asterisk* also includes cows not in milk, calf or breeding, *double asterisks* also include some animals defined as heifers in slaughter statistics). *Bracketed values* are approximate carcass weight equivalents. (Some numbers may not add up due to rounding.) The *number in the dotted box* shows the difference between total born calves and slaughtered animals, indicating the number of animals that died naturally and changes in stocks between years

them. These so-called 'bobby calves' produced around 17 kg CW per head. The number in the dotted box is total born calves minus number of slaughtered animals, to have the total 'animal flows' to match, and indicates the number of animals not presented in slaughter statistics (e.g. animals that died naturally) and changes in stocks between years. In the dairy system, it also included dairy heifers that were retained and reared on non-dairy farms for new dairy farm conversions in NZ.

2.1.2 Sweden

In Sweden 2005, approximately 0.4 million dairy cows produced 3.25 million tonne milk, predominantly for the domestic market. Sweden is part of the EU milk quota system,[2] and total production is slowly decreasing in SE. There is only a small net import of dairy products to Sweden.

The average calculated number of cows per farm in Sweden is 46 cows that are mostly indoors, but in summer (four to five months) also outdoor grazing. The milk delivered from the farm is 8,270 kg ECM cow^{-1} year^{-1}. The replacement rate is 38% for dairy cows, and the heifer has its first calf at 28 months. A dairy cow in SE has an average 2.6 lactations (i.e. the average age for slaughter is about 5 years for a dairy cow).

[2] The milk quota system in EU will end in 2015.

In Fig. 2, the Swedish cattle flows are illustrated. The data in the shaded boxes are for 1 year (2005) and based on national statistics from the Swedish National Board of Agriculture (SJV 2006a, b), Taurus (2006; 2005a, b) and Cederberg et al. (2009a). Based on this, the 'cattle flows' (arrows in Fig. 2) are calculated/estimated. Total number of dairy cows were 393,000 (SJV 2006a), of which 124 000 were slaughtered (Taurus 2006). The total number of calves born and alive after 1 month was 534,000 (SJV 2006b), of which approximately 330,000 were dairy calves. Of the dairy calves, 149,000 stay within the dairy system and replace the culled dairy cows, while 181,000 dairy calves enter the beef system and are raised to slaughter age (on average about 20–22 months) at a weight of approximately 290–310 kg CW (the lower figure is a weighted average of all dairy cattle, excluding dairy cows, while the higher excludes both dairy cows and calves slaughtered before 8 months). The replacement rate for beef cows is around 29%. The number in the dotted box is total born calves minus number of slaughtered animals, to have the total 'animal flows' to match, and indicates the number of animals not presented in slaughter statistics (i.e. animals that died naturally were exported or slaughtered at home) and changes in stocks between years.

2.2 Co-product handling

Six scenarios for handling co-products with either system expansions or different types of allocation are summarised

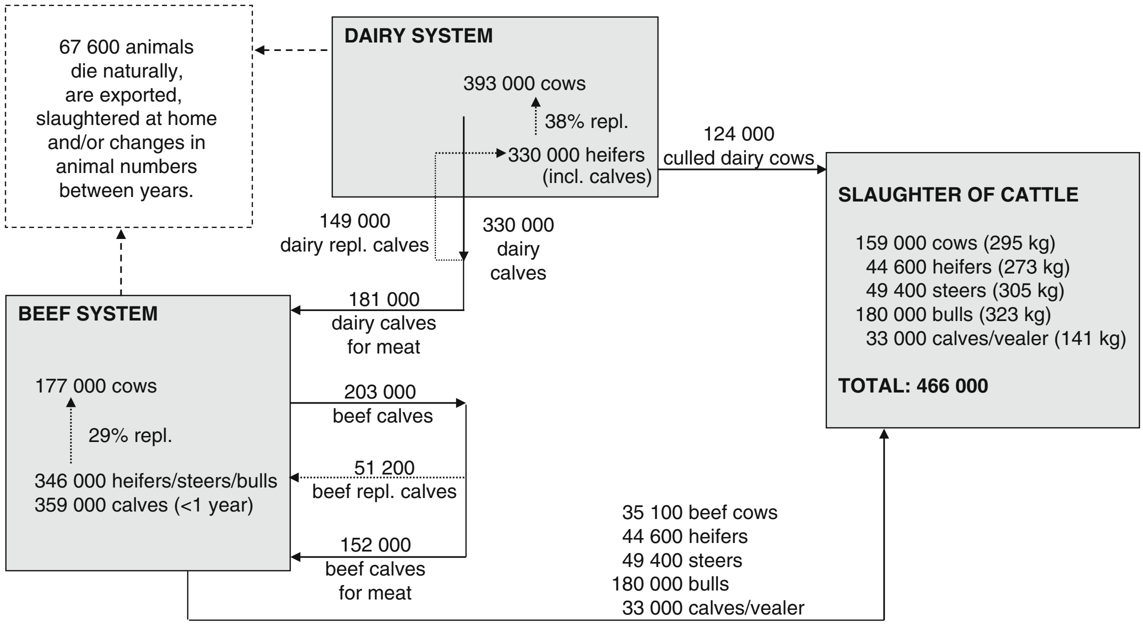

Fig. 2 Illustration of the flows of cattle in Sweden. *Bracketed values* are approximate carcass weight equivalents. (Some numbers may not add up due to rounding.) The *number in the dotted box* shows the difference between total born calves and slaughtered animals, indicating the number of animals that died naturally, were exported or slaughtered at home, and changes in stocks between years

in Table 1 and described in more detail in the sections below.

2.2.1 System expansion

The two main outputs[3] from the dairy system are milk and meat (from slaughtered dairy cows and the 'surplus' calves raised for meat production, in NZ also from bobby calves (slaughtered 4 days old)), as illustrated in Fig. 3. Milk production does not only affect the dairy system, but it is also closely interlinked with the beef production system. If meat production from milk systems decreases, it would affect beef and presumably also other meat production systems. When applying system expansion, the environmental impact of milk would then be: the total induced environmental impact from the dairy system, as well as the raising of a calf ready for slaughter (shaded box to the left in Fig. 3), and the avoided environmental impact from alternative meat production (shaded box to the right in Fig. 3). Since the various types of meat (from cow, raised surplus calf and bobby calf) are of different quality, it is also reasonable to assume they replace different meats (e.g. beef, pork and chicken). System expansion is here applied using two different scenarios: (1) all meat from the dairy system substitutes beef meat, and (2) the various types of meats from the dairy system replace different meat types. In the second case, meat from culled dairy cows (assumed to be of a lower quality) replaces equal amounts of beef and pork, while the meat from the surplus calf raised for beef production replaces beef from a pure beef production system. In NZ, the meat from bobby calves (a relatively white meat) is more similar to chicken than beef, and therefore, this meat is assumed to replace meat from chicken in the second scenario.

Emissions associated with raising a calf to slaughter age are calculated specifically for each country, based on data on feed intake (personal communication, Mark Boyes, AgResearch; Carin Clason, Växa). In NZ, the feed intake was about 5.3 tonnes dry matter intake (DMI) (roughage feed/grass) to raise a calf to the age of 22–28 months (305 kg CW), and in SE, it was 4.6 tonnes DMI (50% roughage feed and 50% grain) to raise a calf to approximately 19 months (313 kg CW). Emissions from enteric fermentation, excreta and manure handling, feed production, etc. were calculated with the same methods as described in Flysjö et al. (2011).

The livestock herd and the meat production from the two system studied are summarised in Table 2. Per kilogram of ECM, the amount of meat is relatively similar for the two systems, but the 'type' of meat differs. Meat from dairy cow comprises a larger share in SE than NZ, while meat from raised calves is similar in both countries (see Table 2). The total beef meat production in NZ (425,000 tonnes) is about five times higher than in SE (88,400 tonnes); however, on a per cow basis, the meat production is twice as high in SE (225 kg per cow) compared to NZ (103 kg

[3] Manure and hides are also outputs, but all manure is here assumed to stay within the system boundaries (i.e. the dairy system), and hides are assumed to be of minor importance and are generally accounted for within the beef component.

Table 1 Different methods for co-product handling used in this study

	NZ	SE
System expansion	Replaces beef	Replaces beef
	Replaces beef, pork and poultry	Replaces beef and pork
Physical causality allocation	86% to milk	85% to milk
Economic allocation	92% to milk	88% to milk
Protein allocation	94% to milk	93% to milk
Mass allocation	98% to milk	98% to milk

per cow), and per ECM, it is approximately the same in both countries (25 and 27 kg per tonne ECM for NZ and SE, respectively). The underlying assumptions are further analysed in Section 4.

The CF numbers of the meats used in the system expansion are 26.4 kg CO2e per CW for beef (from pure beef system), 3.4 kg CO2e per CW for pork and 1.9 kg CO2e per CW for poultry (Cederberg et al. 2009a). The data are Swedish averages at farm gate, but since no data exist for NZ, the figures are used for both systems. Amount of edible meat per CWE differs between beef, pork and poultry, and this is accounted for in the study assuming 70%, 59% and 75% edible meat per CWE for beef, pork and poultry, respectively (personal communication, Katarina Nilsson, the Swedish Institute for Food and Biotechnology).

2.2.2 Physical causality allocation

Allocation based on physical causality is based on the guidelines from IDF (2010) and accounts for the feed energy demand, needed for producing milk and meat (dairy cow and calves), respectively. The allocation factor for milk is calculated (using the equation provided in IDF (2010)) to 86% for NZ and 85% for SE.

2.2.3 Economic allocation

The economic allocation is based on the value for milk and animals (cows and calves) at farm gate, i.e. the value the farmer receives, using a 5-year average (i.e. 2003 until 2007). For NZ, the economic allocation factor for milk is 92% (Ledgard et al. 2009b) and for SE 88% (Farm Economic Survey).

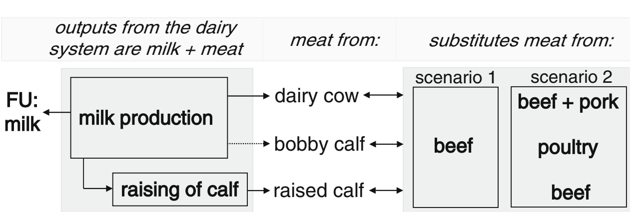

Fig. 3 Illustration of the system expansions applied in this study

2.2.4 Protein allocation

Protein allocation is based on edible protein in milk and meat (from culled dairy cows and surplus calves) (CWE is used for the meat). The amount of protein in ECM is assumed to be 3.3% and in meat (CWE) about 20%. Thus, the protein allocation factor for milk is 94% and 93% for NZ and SE, respectively.

2.2.5 Mass allocation

Allocation is also performed based on mass, i.e. on the total weight of milk and of animals (live weight of culled dairy cow and surplus calves) that leave the farm gate. The mass allocation factor for milk is 98% for both NZ and SE.

3 Results

There is a large variation in the calculated carbon footprint of milk depending on how emissions are divided between co-products (see Fig. 4). Applying system expansion results in a significantly lower CF than any of the allocation alternatives. The various allocation factors range from 85% (physical causality allocation in SE) to 98% (mass allocation), resulting in more than 10% difference in the final CF values, depending on which allocation method (physical causality, economic, protein or mass) is used. Mass allocation resulted in the smallest difference (2% less) compared to when 100% of the emissions are allocated to milk (i.e. milk carries the whole burden). No matter which method is applied for co-product handling, SE milk has a higher CF than NZ milk. However, applying economic allocation results in 9% higher CF for SE than NZ, while for mass allocation (or when all emissions are allocated to the milk), it is 16% higher.

The results clearly show that applying system expansion methodology depends highly on what type of meat is assumed to be replaced. In the first system expansion, all by-products (meat) were assumed to replace beef, while in the second case, different meats were replaced to account for the quality of the meats. Since beef has a considerably

Table 2 Number of dairy animals alive and slaughtered for NZ and SE respectively (in total, per dairy cow and per tonne ECM)

Number of animals	Total		Per cow		Per tonne ECM	
	NZ	SE	NZ	SE	NZ	SE
Dairy cows	4,120,000	393,000	1.00	1.00	0.243	0.121
Dairy heifers	917,000	330,000	0.223	0.839	0.0540	0.101
Dairy calves to beef system	955,000	181,000	0.232	0.460	0.0563	0.0556
Slaughtered dairy cows	688,000	124,000	0.167	0.316	0.0406	0.0382
Slaughtered raised dairy calves	864,000	181,000	0.210	0.460	0.0509	0.0556
Slaughtered dairy bobby calves	1,420,000	–	0.344	–	0.0835	–
Weight of slaughtered animals (kg CWE)						
Meat from dairy cows	138,000,000	35,900,000	33.4	91.3	8.11	11.0
Meat from raised dairy calves	263,000,000	52,500,000	63.9	133	15.5	16.1
Meat from dairy bobby calves	24,100,000	–	5.85	–	1.42	–
Total meat	425,000,000	88,400,000	103	225	25.1	27.2

higher CF than pork and poultry, the first system expansion resulted in a lower CF for the milk.

4 Discussion

The results show that the ranking of the CF numbers is the same between the countries, as long as the same co-product handing method is used, i.e. NZ has a lower CF per kilogram milk than SE. It is also notable that the amounts of meat per kilogram of milk from the two systems are quite similar (25.1 and 27.2 gram per kilogram milk for NZ and SE, respectively). There is however a larger number of dairy calves per kilogram milk in NZ, but since the majority of the surplus dairy calves are slaughtered as bobby calves, the amount of meat from those is relatively low. In SE, a larger share of meat comes from the slaughtered dairy cow, primary due to the higher replacement rate in SE compared to NZ. The number of dairy calves going into beef production and the number of slaughtered dairy calves (shown in Table 2) are approximately the same for SE, while there is a larger difference for NZ. This is due to a decrease in dairy cows over time in SE, while the dairy herd is increasing in NZ. Thus, matching cattle flows for 1 year is quite difficult since the lifetime of the animals typically is more than 1 year and there are changes in stocks between years. It has not been possible to disaggregate the number of animals that died naturally, was exported or slaughtered at home, and the changes in number of animals between year (dotted box in Figs. 1 and 2). However, even though this disaggregation would be interesting, it is considered to have minor impact for the outcome of this paper.

In the two scenarios for the system expansion, where by-products (slaughtered dairy cow and surplus calves) substitute (1) only beef meat and (2) a mix of meats, CF data (on beef from suckler cow system, pork and poultry) from a Swedish study have been used, and these might not be representative for NZ. However, the magnitude of CF numbers of different meats (beef, pork and chicken) is likely in the same order, and thus, the purpose was to illustrate the importance of what type of meat is substituted

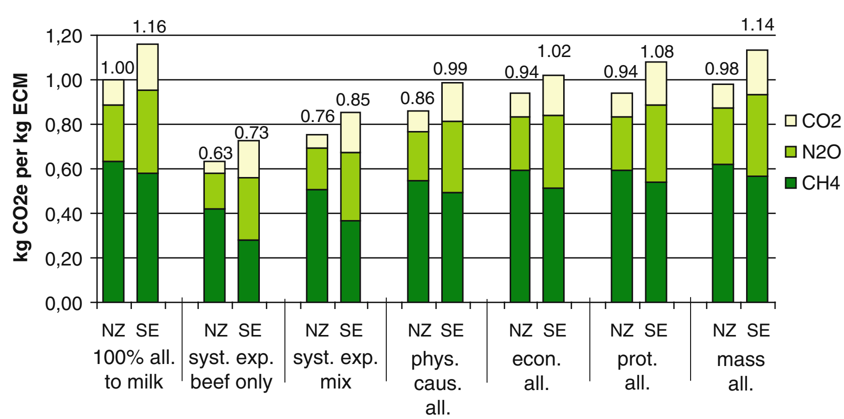

Fig. 4 CF for one kilogram milk in NZ and SE, applying different methods of handling the co-product meat of no allocation (i.e. 100% of emissions are allocated to milk), system expansion replacing beef only, system expansion replacing a mix of meat, physical causality allocation, economic allocation, protein allocation and mass allocation

the conclusions are expected to be the same, even if country specific figures were used. Weidema (2003) defines product substitution (here system expansion) as replacing one product with another product, which fulfils the *same needs* of the customer. Hence, the quality of the meat should be considered when applying system expansion.

4.1 The need for harmonising co-product handling

LCA/CF is a valuable tool for analysing the environmental impact and GHG emissions from products and systems. Using a CF number in communication can be useful, but it is important to know the consequences of decisions and methodology, and how they impact the outcome of the results. The present study showed a significant difference in the final CF results for milk, depending on how the by-product meat was accounted for. According to ISO (2006), system expansion is the first choice of co-product handling method, which would be applicable for milk studies. However, depending on the goal and scope of the study, different methods for co-product handling can be applied. System expansion is typically used in consequential LCA (CLCA) modelling, while allocation is often used in attributional LCA (ALCA) modelling. In CLCA, the consequences of a change is always analysed, e.g. if milk is produced compared to if milk is not produced. Thus, in the second case, the same amount of meat (that is by-product in the first case) needs to be produced in some other way, since the only change one wants to analyse is the milk. ALCA is more about recording physical flows and to attribute the emissions between co-products, e.g. if a country is reporting their GHG emissions and wants to analyse the share of each sector, some sort of allocation factor would be needed. However, when *comparing* CF numbers, it is crucial that the same method for handling co-product is applied, if conclusions should not be misleading.

For example, if a consumer has the possibility to chose between (1) milk produced in New Zealand, labelled with a CF number based on the methodology in PAS 2050 specifically applied to the dairy sector (Carbon Trust, 2010) (e.g. 0.94 kg CO2e per kilogram milk) or based on the PCR[4] from the Swedish Environmental Management Council (2010) (e.g., 1.00 kg CO2e per kilogram milk), and (2) milk produced in Sweden, labelled with a CF number based on the allocation procedure in ISO (e.g. 0.85 (or 0.73) kilogram CO2e per kilogram milk), an environmental friendly consumer would likely choose the Swedish milk thinking that it was the right choice (Table 3). However, the difference in CF numbers would only be a result of different methodology for co-products handling, and the milk from NZ would likely have a lower or similar CF. Thus, depending on which standard/guideline the LCA/CF performer choose to use, the CF result for milk will differ. Consequently, before CF can be used in communication (e.g. labelling), there is an obvious need for harmonised guidelines on methods for co-product handling. (There are also other areas of difference crucial to consider when calculating the CF; hence, harmonisation is needed for several areas, not only co-product handling.)

4.2 Milk and beef—an integrated production

As mentioned previously, it is crucial to be aware of the fact that the dairy system does not only affect milk production but also meat production, as the majority of dairy calves are surplus calves (i.e. are not raised to become dairy cows) and slaughtered for the meat. Also, culled dairy cows represent a significant share of the global cattle meat production. Approximately 65% of the beef production in both NZ and SE originates from the dairy sector in 2005. According to FAO, the dairy sector is estimated to represent as much as 57% of the global cattle meat production (Gerber et al. 2010). There is an ongoing trend for intensification of milk production per cow, which results in less meat production per kilogram of milk. In an analysis of the environmental improvement potentials of meat and dairy products in Europe, Weidema et al. (2008) concludes that an intensification of milk production through increased milk yield per cow would lead to reduced methane emissions per kilogram of milk (−24%), but would not lead to any significant reduction in GHG emissions (−0.27%) in total, due to an "induced additional beef production from suckler cows necessary to keep the meat output unaltered". Also, intensification may lead to an increase in impacts for most of the other environmental categories (Weidema et al. 2008). In Sweden, a study has been conducted, analysing the GHG emissions from animal production and consumption in Sweden for 1990 and 2005 (Cederberg et al. 2009a, b). The production of both milk and beef meat in Sweden has been relatively stable during the period. There has however been a shift in production; in 1990, 85% of all beef had its origin in the dairy sector, but this was reduced to 65% in 2005, due to an intensification of milk per cow (which resulted in a reduction in number of dairy cows, since EU, including SE, has a quota system not allowing more milk to be produced). Thus, more effective milk production resulted in less emissions per kilogram milk, but more emissions per kilogram beef (due primarily

[4] The Product Category Rule (PCR) for processed liquid milk states that meat from slaughtered cows and calves "shall be omitted considering that the useful meat (kg) is negligible" (Swedish Environmental Management Council, 2010), which is here interpreted as 100% of emissions shall be allocated to milk and none to meat. In the former PCR for milk and milk-based products (Swedish Environmental Management Council, 2006), mass allocation was recommended.

Table 3 CF results (kilogram CO2e per kilogram ECM) for milk in NZ and SE depending on method applied for co-product handling according to different standards/guidelines

Standards/guidelines	NZ	SE	Ranking according to ISO
ISO (system expansion)	0.76 (0.63)	0.85 (0.73)	1
IDF (physical causality)	0.86	0.99	2
PAS 2050[a] (economic)	0.94	1.02	3
PCR to EPD[b] (no all/mass)	1.00/0.98	1.16/1.14	(3)[c]

The figures for system expansion are based on the by-products (meat from culled dairy cows and surplus calves) substituting for a mix of meats (and in brackets beef meat only)

[a] The preferred approach in PAS 2050 (BSI, 2008) is system expansion, but in the methodology report specifically for dairy (developed by Carbon Trust, who also developed PAS 2050), economic allocation is recommended to divide GHG emissions between milk and meat; thus, to our understanding, economic allocation should be applied for milk and meat if following PAS 2050

[b] The Environment Product Declaration, EPD, system is an international tool to communicate the environmental performance of products. In the latest PCR on milk from 2010, the recommendation is that the by-product meat shall be omitted (here understood as 100% shall be allocated to milk, i.e. 'no allocation') while mass allocation is recommended in the PCR from 2006

[c] Mass allocation goes under the third option in ISO, and obviously reflect a physical (however not *underlying* physical) relationship, but must be seen as less appropriate than economic allocation for milk production

to an increase in suckler cows (SJV) to compensate for the reduced number of dairy cows, see Fig. 5). Applying physical causality allocation, the average CF per kg milk in Sweden was reduced by about 20%, while the CF per kilogram beef increased by 10% between 1990 and 2005 (Cederberg et al. 2009a). However, the reduced emissions due to intensification of the dairy sector were still sufficient to compensate for the increased emissions from the beef sector. Thus, in total, there was a reduction in GHG emissions from Swedish production of milk and beef meat. During the same period, there was an increase in meat consumption (dairy products were relatively stable) in Sweden, and the consumption of beef increased by almost 50% per capita, which was met by increased imported beef (which resulted in an increase in GHG emissions for animal consumption in Sweden (Cederberg et al. 2009b)). Today, about 40–50% of the beef meat consumed in SE is imported, primarily from Ireland and Brazil. Thus, to benefit from the reduced emissions due to the intensification in milk production, there also needs to be a reduction in (beef) meat consumption.

As seen in Fig. 5, the development in milk production and number of cows in NZ are rather different compared to SE. In contrast to SE, NZ is a large exporter of both dairy products and beef, accounting for 25% and 5% of NZ merchandised exports respectively in 2007 (MAFa). In NZ, there has been a steady growth in total milk production, mainly due to an increased number of dairy cows, but also due to higher milk yield per cow. During the same period, there has been a slight decrease in beef cows. As many calves are slaughtered as bobby calves, it gives an indication that there is an excess of calves in NZ. Many of these are Jersey calves considered less suitable for beef, and there is no economic incentive in raising them for

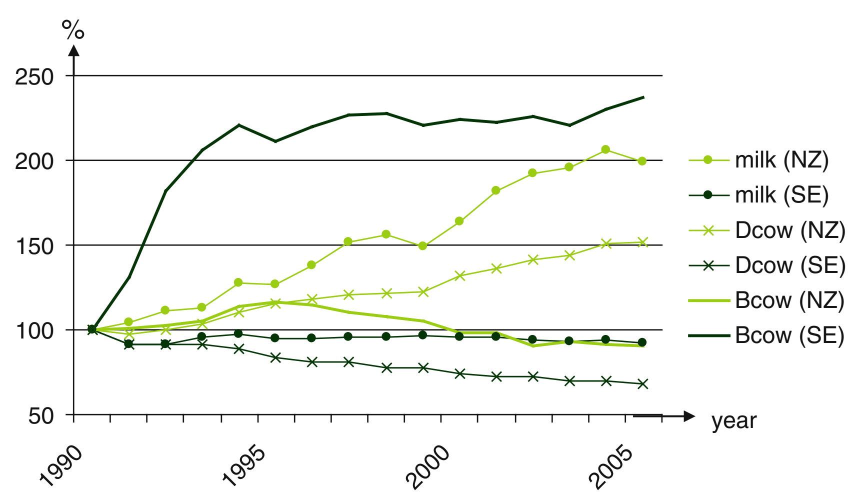

Fig. 5 Relative change in milk deliver (*milk*), number of dairy cows (*Dcow*) and beef (suckler) cows (*Bcow*) in NZ and SE, respectively, between 1990 and 2005 (LIC 2008; SJV 2000; SJV 2006c, MAFb, SJV)

producing more meat (even though it could be an environmental benefit). This farmer choice will be influenced by the relative prices for meat and milk.

The global demand for animal protein is estimated to increase by 50% in 2020 and to double in the year of 2050 (FAO 2006), and the dairy sector will be very important in this development. To analyse how to best provide a growing population with animal protein, a system analysis approach is needed, including all animal sectors, and milk and beef must be studied in an integrated way since the production systems are so closely interlinked. Depending on the prognoses for the future demand of milk and beef meat, the scenarios of the best ways of providing these animal foods might be different. If the demand for beef is expected to increase, while the demand for milk is increasing to a lesser extent, it can be questionable if intensification is the best option for keeping the total GHG emissions down. If milk, on the other hand, would be expected to increase more than beef, intensification might be the right choice. In some parts of the world, however, intensification would contribute both to food security and to reduction of emissions per product unit.

5 Conclusions

When assessing the CF of milk, it is important to account for by-products, i.e. meat from the culled dairy cows and surplus calves (representing 57% of global beef production, Gerber et al. 2010). The methodological choice for handling this by-product is crucial for the outcome of the CF result of milk and dairy products. The present study showed that system expansion results in a significantly lower CF number for milk (63–76%), compared to when 100% of the emissions are allocated to milk (i.e. milk carries the whole burden). All other analysed allocation methods gave a higher CF number compared to system expansion: between 85% (physical causality allocation in SE) and 98% (mass allocation). System expansion is the first choice of co-product handling method according to ISO that is applicable to LCA of milk. It is however important what products (type of meats: beef, pork or chicken) are replaced, as this influence the final results. Despite the existing standards and guidelines on LCA/CF methodology, there is still no shared understanding on co-product handling. Thus, if CF numbers of milk need to be compared, it is crucial that the same method for co-product handling is used.

To analyse how to best provide a growing population with animal protein, a system analysis approach is needed that includes all animal sectors. Depending on the outlooks for the future demand of milk and beef meat, the scenarios of the best ways of providing these animal foods might be different. Hence, production of milk and beef must be studied in an integrated way since the production systems are closely interlinked.

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